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Online Experimentation and Interactive Learning Resources for Teaching Network Engineering

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Abstract—This paper presents a case study on teaching network engineering in conjunction with interactive learning resources. This case study has been developed in collaboration with the Cisco Networking Academy in the context of the FORGE project, which promotes online learning and experimentation by offering access to virtual and remote labs. The main goal of this work is allowing learners and educators to perform network simulations within a web browser or an interactive eBook by using any type of mobile, tablet or desktop device. Learning Analytics are employed in order to monitor learning behaviour for further analysis of the learning experience offered to students.

Keywords—open educational resources, online experimentation, interactive learning resources, network engineering, learning analytics.

I. INTRODUCTION

ICT is becoming a pervasive platform for the global economy and society. There are now over 3 billion Internet users worldwide¹ with the number of smartphones set to surpass 2 billion by 2016² growing to 6 billion by 2020.³ In the next few years, 5G connectivity will bring 10GB bandwidth to these mobile platforms with high reliability and almost no blackspots. An ICT skilled workforce and a digitally literate society is key to fulfilling the full potential for digital technologies. There exists however a significant ICT skills gap.

For example, it is estimated that there will be 756,000 unfilled vacancies for ICT professionals in Europe by 2020.⁴ Despite the fact that 90% of future jobs will require ICT skills 60% of students never use digital equipment in the classroom.⁵ As Neeli Kroes (former EU Vice-president and Digital Agenda Commissioner) commented recently on the EU ICT job market situation:

If we can't fulfill the almost million job vacancies it will harm our economy, make it less competitive. Already ICT

companies are looking outside Europe, and they are welcome there. This situation could lead to losing entire countries.

From an educational perspective, recent years have also seen some exciting developments. The 'Cloud Schools' programme, initiated in 2014 and supported by a \$1M TED grant enables children from some of the poorest villages in India to be taught by volunteer retired teachers across the globe through Skype.⁶ Recent times have also seen the rise of Massive Open Online Courses (MOOCs) providing world class online learning for free giving students access to rich multimedia materials delivered by academics from the best universities. With a history beginning with the Open Educational Resource (OER) movement MOOCs burst onto the educational scene in 2012 with the New York Times declaring it the 'Year of the MOOC'.⁷ Companies such as Udacity⁸ and Coursera⁹ from Stanford and edX¹⁰ from MIT have seen online registrations grow very quickly. As of March 2015, Coursera has over 12 million learners. Closer to home, the Open University's MOOC company FutureLearn¹¹ which began offering courses in late 2013 now has just under 5 million learners.

This paper presents a case study on teaching network engineering via online experimentation and interactive learning resources. This case study has been developed in the context of the FORGE project,¹² which is a European initiative for online learning and experimentation via interactive learning resources. FORGE provides learners and educators with access to world-class experimentation facilities and high quality learning materials via a rigorous production process [1, 2]. As part of this initiative, we have been collaborating with the Cisco Networking Academy¹³ in order to produce a series of interactive learning materials based on Cisco's renowned educational software for network simulations.

The remainder of this paper is organised as follows. First, related work in the areas of online experimentation, Learning Analytics and mobile learning is presented. The pedagogical

¹ <http://www.internetlivestats.com/internet-users/>

² <http://www.telegraph.co.uk/technology/mobile-phones/11287659/Quarter-of-the-world-will-be-using-smartphones-in-2016.html>

³ <http://www.gsma.com/newsroom/press-release/smartphones-account-two-thirds-worlds-mobile-market-2020/>

⁴ <https://ec.europa.eu/digital-single-market/en/skills-jobs>

⁵ <https://ec.europa.eu/digital-agenda/en/skills-jobs>

⁶ <https://www.theschoolinthecloud.org>

⁷ http://www.nytimes.com/2012/11/04/education/edlife/massive-open-online-courses-are-multiplying-at-a-rapid-pace.html?pagewanted=all&_r=1

⁸ <https://www.udacity.com/>

⁹ <https://www.coursera.org/>

¹⁰ <https://www.edx.org/>

¹¹ <https://www.futurelearn.com/>

¹² <http://ict-forge.eu>

¹³ <http://www.netacad.com>

and technological background of this work is then introduced, followed by the methodology for the development of interactive learning resources within FORGE. We then present the developed widget and the learning materials complementing it, its software architecture, as well as its Learning Analytics infrastructure. Finally, we conclude the paper with our findings and the next steps of this work.

II. RELATED WORK

Online experimentation and remote/virtual labs offer rich learning opportunities by allowing learners to control real or virtual equipment at distance in order to conduct scientific experiments. Remote/virtual labs build on top of numerous emerging technologies for supporting online experimentation and promoting the immersion of the learner in virtual environments recreating the real experience. There are different available methodologies in the literature for deploying remote/virtual labs, each of them targeting different facilities and tools. Bose [3] presents a methodology for creation of a virtual lab. This approach targets the Virtual labs project and guides the lab creator to deploy a lab within the scope of such project. In a similar basis, Frerich et al [4] present a lab lifecycle with the Excellent Teaching and Learning in Engineering Sciences (ELLI) project. Both these projects, focus on virtual labs (software/simulation-based) rather than remote experimentation labs (experimentation-based) [5]. Additionally, the European project Go-Lab¹⁴ focuses on virtual labs in the context of inquiry-based learning mainly targeted to Secondary Education.

Learning Analytics has recently emerged as a new field with applications on remote labs and beyond. Siemens [6] defines Learning Analytics as “the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs”. The field of Learning Analytics is rapidly developing and it gradually shifts away from technology towards an educational focus [7]. It applies techniques from information science, sociology, psychology, statistics, machine learning, and data mining to analyse data collected during education administration and services, teaching, and learning. Learning Analytics creates applications that directly influence educational practice. For example, the OU Analyse project deploys machine-learning techniques for the early identification of students at risk of failing a course [8]. The Go-Lab project employs Learning Analytics in order to foster awareness, create individual scaffolds for students as well as support teachers in monitoring learning activities and better informed decision making [9].

Finally, mobile learning offers opportunities for new learning experiences outside the classroom and encourages new forms of collaboration among learners [10]. Learners are involved in real problem-solving situations, which provide the motivation to collaborate with other learners. Learners can extend their classroom learning to homework and field trips,

e.g. by reviewing learning materials on their mobile devices or by collecting and analysing data using dedicated mobile apps [11]. In the context of remote labs, mobile learning enables learners to perform scientific experiments, either individually or collaboratively, wherever they are without the need for access to a traditional desktop or laptop device.

III. PEDAGOGICAL AND TECHNOLOGICAL BACKGROUND

Packet Tracer¹⁵ has become an established pedagogical network simulation tool used by the global Cisco Networking Academy educational community [12]. With around 50,000 uses per day and a reach of 1,000,000 users,¹⁶ Packet Tracer is typically used in situ to offer students experience of a diverse range of networking protocols, networking technologies and their interactions.

Based on Scandinavian activity theory [13], Packet Tracer extends the learning experience and zone of proximal development (ZPD) of nascent network engineers [14]. This is accomplished by creating different simulated contexts via the medium of Packet Tracer. Guiding the student through the practical experience of building and troubleshooting complex network systems as the tool/tool-mediator using the rules of the networking protocols and technologies in situ. The ZPD moves from the master/apprentice in the classroom to the master/apprentice experience of the created simulated scenarios offered to students via Packet Tracer to develop their professional and practical skills in network engineering.

Historically, the tradition of skills development and knowledge acquisition in network engineering focused on a hands-on experience using real networking equipment. The Cisco Networking Academy programme among others created a cadre of curriculum embedded labs (practical exercises) that emulated industrial experience and honed the required skills.

Packet Tracer allows the teacher to create different practical ‘cognitive apprenticeship’ scenarios of differing complexity and deliver these to their student. Either in class or remote for completion. An affordance of Packet Tracer is its ability to model networks as well as mark as complete the practical work completed by students [15]. Giving positive feedback and an assurance that they are progressing towards completing a set learning goal.

Also contained within Packet Tracer is an API which includes remote connectivity. In a face-to-face learning scenario, a teacher can encourage their students to create individual complex networks on each instance of Packet Tracer, before interconnecting each instance, using the multi-user tool within the classroom. This enables teachers to extend the scope of each student created network infrastructures, introducing students to the experience of interconnecting disparate network systems (see Figure 1).

¹⁴ <http://www.go-lab-project.eu>

¹⁵ <https://www.netacad.com/about-networking-academy/packet-tracer>

¹⁶ <https://www.netacad.com/get-started/employers/>

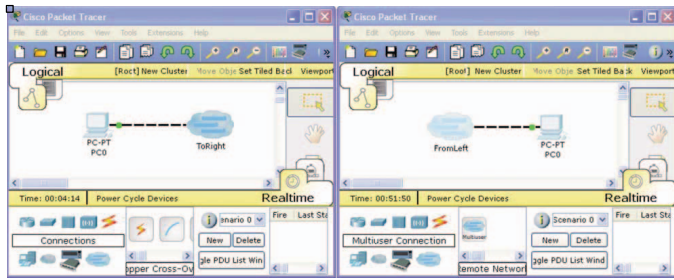


Figure 1. An example of Packet Tracer multi-user communication [16].

IV. BUILDING INTERACTIVE LEARNING RESOURCES

One of the main goals of the FORGE project is to enable educators and learners to access and actively use online experimentation facilities in order to conduct scientific experiments. We thus follow a constructivist approach to education where learning takes place by students creating artefacts rather than assuming the passive role of a listener or reader. Our approach is based on a wide range of studies that have shown that with the right scaffolding competent learners benefit greatly from constructivist or learning-by-doing approaches [17-19]. The experiment-driven approach of FORGE contributes to fostering constructivist learning by turning learners into active scientific investigators, equipped with world-class experiment facilities.

From a learning technology perspective, FORGE is building upon new trends in online education. More specifically, in online educational platforms such as iTunes U, as well as in MOOCs, we see the large-scale take-up and use of rich media content. These include video in a variety of formats including webcasts and podcasts and eBooks, which can contain multimedia and interactive segments. In particular, eBooks provide a new level of interactivity since specific learning text, images and video can be closely integrated to interactive exercises.¹⁷

Additionally, the FORGE learning resources are offered to learners and educators as Open Educational Resources (OERs). OERs can be described as “teaching, learning and research resources that reside in the public domain or have been released under an intellectual property license that permits their free use or repurposing by others depending on which Creative Commons license is used” [20]. The emergence of OERs has greatly facilitated online education through the use and sharing of open and reusable learning resources on the Web. Learners and educators can now access, download, remix, and republish a wide variety of quality learning materials.

FORGE is enabling students to setup and run online experiments from within rich related learning content embedded as widgets inside interactive learning resources. Widgets are powerful software components that can be reused across different learning contexts and for different educational

purposes. They offer a simple interface and can accomplish a simple task, such as displaying a news feed. They can also communicate with each other and exchange data, so that they can be used together to create mashups of widgets that complement each other. The portability of widgets as bespoke apps that can be embedded into a variety of online environments ensures that the FORGE learning solutions implemented as widgets have a high reusability factor across multiple learning domains and online learning technologies. Within FORGE, widgets enable educators and learners to access and actively use online experimentation facilities as remote labs. Learners and educators can setup and run their experiments from within rich related learning content embedded as widgets inside interactive eBooks and Learning Management Systems.

V. PT ANYWHERE

A. Development of bespoke widget and OERs

The Open University is one of the partnering institutions of the Cisco Networking Academy in the UK, delivering a variety of networking courses to its students. Building upon this partnership in the context of the FORGE project, we are developing bespoke interactive learning resources that are offered as self-study OERs to learners and educators, who wish to get a taste of what the Cisco Networking Academy has to offer. These OERs introduce learners to the basics of network equipment and configuration. They can be accessed online and downloaded in the form of an interactive eBook.¹⁸

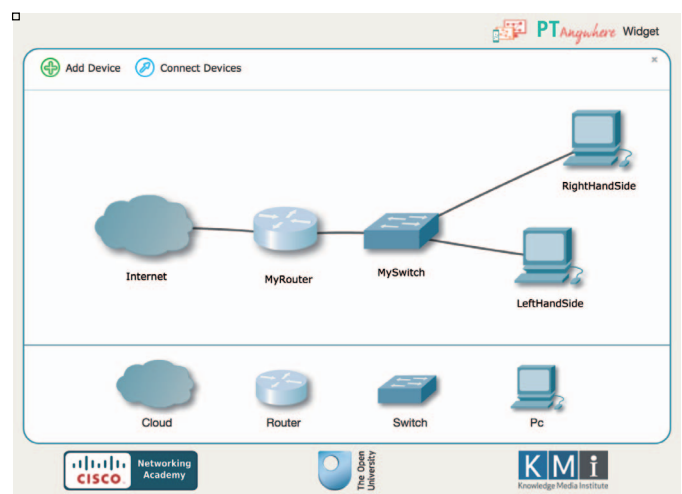


Figure 2. The PT Anywhere widget interface.

In order to allow learners to use Packet Tracer in the context of the FORGE OERs, we have developed a bespoke web interface on top of Packet Tracer, called PT Anywhere.¹⁹ PT Anywhere offers a network simulation environment via a web

¹⁷ <http://vimeo.com/98431150>

¹⁸ <https://itunes.apple.com/us/book/id1062612920>

¹⁹ <http://pt-anywhere.kmi.open.ac.uk>

interface that can be accessed from any web browser or as a widget inside an interactive eBook. Rather than replicate Packet Tracer's functionality in a web application, PT Anywhere is offering its basic functionality from a minimalistic interface that can be adapted to different learning contexts and purposes. PT Anywhere is available as a widget that can be embedded inside an online course, a Learning Management System, or an interactive eBook.

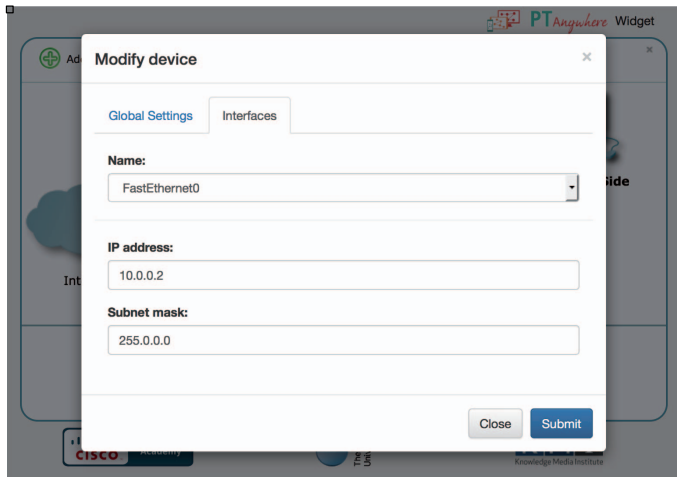


Figure 3. Modifying the settings of a device in PT Anywhere.

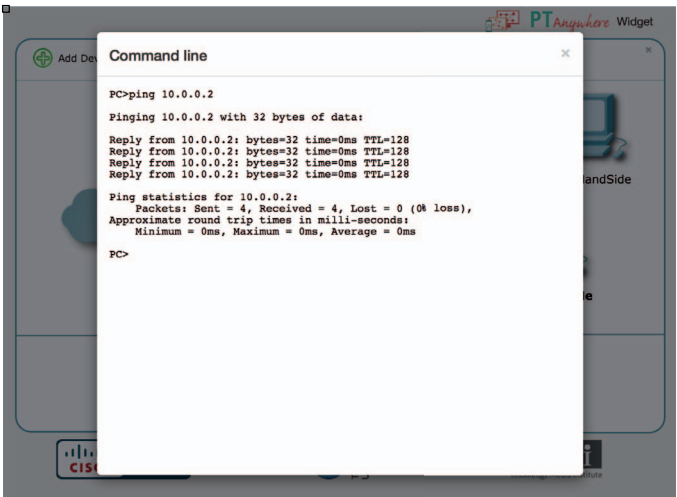


Figure 5. The command line interface of PT Anywhere.

Figure 2 shows the PT Anywhere widget interface. Learners are presented with a single router, a single switch and two personal computers. The ‘Internet’ in this context is a connection to the underlying remote Packet Tracer server offering connectivity on the simulated internet. With a single router, learners can see an entire network infrastructure as well as complete a range of complex networking skills. Learners can also modify the settings of a device (see Figure 3) and launch a command line interface in order to execute terminal commands (see Figure 5).

out there, but you cannot see it from here". Behind this cloud icon, we have hidden some network technology. This may be on a remote server or locked away inside this eBook.

The Network Server

Learning about servers are an entire eBook in their own right; as are each of the other technologies in this section. We will give you a very brief introduction, to help you understand a little more about your simulator and network technology.

The google definition of server is "a computer or computer program which manages access to a centralised resource or service in a

@teraknor

Figure 5.4
Representation of a network server in Packet Tracer.

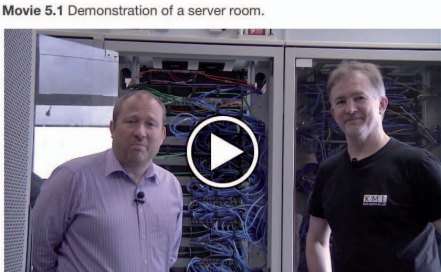
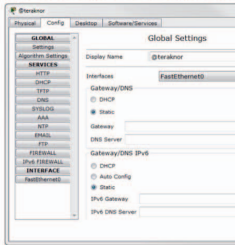


Figure 5.5 List of protocols used in Packet



network". For the purposes of this eBook, I description, but you will discover Network that will tell you that there is much more to t

Often servers have been used to help us wi of files. Somewhere on the internet, then copies of this eBook that you downloaded you visit a web page, a web site or use a You are interacting remotely with a server.

We also use servers for to support the ma our networks running. Domain Name Servic link the names of web sites to the IP (intern of these servers. Don't panic, during the pr this eBook we will give you a little bit m addresses.

If you look at Figure 5.5, you can see some of the protocols used in Packet Tracer. Why not use a search engine to discover what FTP, TFTP, DHCP, NTP and HTTP all do.

Servers come in different shapes and sizes, as you can see in the server room demonstration of Movie 5.1. In this video, Andrew Smith from the Faculty of Mathematics, Computing and Technology of the Open University and Ben Hawkridge from the Knowledge Media Institute of the Open University show the equipment typically found in a server room and discuss its usage.

The Router

Routers normally sit at the edge of your network. Their role is to move packets of data at high speed across a larger network such as the internet. Before your data leaves your device (such as your personal computer or a tablet device), it is split into many packets to aid transit across the network.

Commercial routers are programmed with a form of simple artificial intelligence called a routing protocol. It is the job of the router, when communicating with other routers to learn the best route to send your network traffic. Like a highway system in your country, network lines of communication can become congested, blocked or in the case of networks a connection to another system goes down. Where the router will attempt to learn a better



Cables

Many networks are still wired, often corporate systems, core network communications and academic networks still use cables. Wireless has become more common, but this is something we will find at the edge of the network. We still need to connect a wireless router to your cabled broadband service.

Packet Tracer has different types of cables and there are different rules for these cables depending on the technology you use. You will have a pre-cabled network on this eBook. Nevertheless, it



Figure 4. Screenshots from the eBook version of the FORGE OERs featuring video demonstrations of different types of network equipment.

Within the FORGE OERs, learners use PT Anywhere in order to simulate different types of networks and understand how network technologies work and interact with each other. These simulations are presented to learners in the context of interactive exercises, thus offering reflection and self-assessment opportunities throughout the learning resources. Learners are also provided with a variety of instructional videos demonstrating the use of network equipment (see Figure 4).

B. Software architecture

The front-end of PT Anywhere is invoked by the HTTP clients of learners. These clients can be normal browsers or browsers embedded in an eBook. The front-end is a JavaScript library which generates the HTML graphical components needed to interact with a Packet Tracer instance running in the back-end. This library makes requests to a public HTTP API²⁰ which abstracts the back-end. For each client, the API intermediates with an actual Packet Tracer instance managed by a machine called Packet Tracer Manager (PTM). The API relies on one or more PTMs to allow horizontal scalability.

Each PTM can handle one or more Packet Tracer instances and exposes an internal API to abstract this functionality. Each Packet Tracer instance will run in its own isolated lightweight Docker container.²¹ Containers are pre-started to reduce the session initialization time. Furthermore, PTM reuses containers from expired sessions because this alternative is faster than discarding an old container and creating a new one. Clients will be unaware of this reuse as a base topology is always loaded at the beginning of every session.

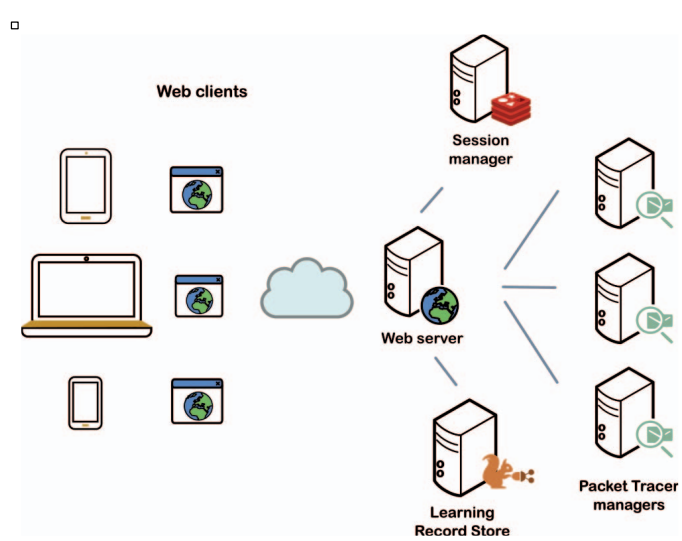


Figure 6. The PT Anywhere architecture.

²⁰ <http://forge.kmi.open.ac.uk/swagger-ui/>

²¹ Docker Containers allow to create independent execution environments which run on a single machine, share the same operating system kernel, are constructed from layered filesystems and

The API stores session specific data in what we called Session manager (see Figure 6). This manager is a Redis instance with two databases. The first one stores the minimal amount of information needed to identify the Packet Tracer instance being used by the session and the second one can be optionally used as a cache to speed up Packet Tracer information retrieval.

The API offers also the ability to record the student interaction in a Tin Can API compliant Learning Record Store. For our installation, we have used an open-source implementation called “Learning Locker” which relies on MongoDB. This has allowed us to use the more expressive and faster Aggregation API²² as a querying mechanism.

C. Learning Analytics

One of the pillars of PT Anywhere is the learning data it records. This data helps to assess students’ performance and to discover non-obvious usage patterns which can be used to improve the OERs and PT Anywhere itself.

The Learning Record Store used to store and manage this information is Learning Locker (LL). LL provides a Tin Can API (also known as xAPI), a specification well accepted by the learning community which aims at enhancing SCORM in simplicity and flexibility. The Tin Can API records data in so called statements which conceptually capture a learning activity. These statements are composed by the following elements: subject, verb, activity, result and context (see Table 1).

Table 1. Tin Can API data recorded by PT Anywhere.

<i>Subject</i>	Anonymized ID. Reused from a previous session ID if possible.
<i>Verb</i>	Initialized, terminated, created, deleted, updated and used.
<i>Activity</i>	Widget, Device, Link and Command line.
<i>Result</i>	Specific for an activity instantiation. It has general data and application specific information (discouraged because it does not promote interoperability).
<i>Context</i>	Session ID and activity categorization.

The subject identifies who is learning. In PT Anywhere, students are anonymously identified. However, the web application tries to reuse an old anonymous ID if it has been previously stored in the browser. This allows us to map possible sessions of the same student.²³

share common files. This allows them to use less RAM and optimize disk usage.

²² <https://docs.mongodb.com/manual/aggregation/>

²³ Although this is only true under the assumption that the same browser has not been shared between multiple students.

Verbs define the type of action that the student carried out. Reusing existing verbs is a good practise because it can ease the interoperability with other systems. In PT Anywhere, we have used the following verbs from the Tin Can API registry:²⁴ initialized, terminated, created, deleted, updated and used.

The learning activities recorded by PT Anywhere are Widget, Device (in the topology), Link (between devices) and Command line (a command line started for a simulated device). These activities have an associated result which identifies details for a particular activity instantiation. E.g., the name and type of the created device.

Finally, the context stores a session ID or categorizes activities (e.g., a “Device” is a “Simulation activity” descendant). Note that more extensive documentation can be found in the PT Anywhere web page.²⁵

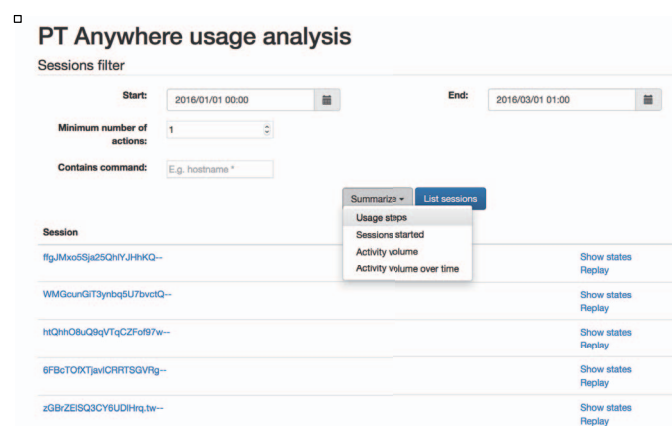


Figure 7. The starting page of the PT Anywhere Learning Analytics dashboard.

The dashboard shown in Figure 7 has been developed in order to help teachers and students in carrying out exploratory analysis of the recorded data. The dashboard filters the data recorded by PT Anywhere by date or other features such as the number of commands typed or the text typed in the simulated command line. The dashboard offers several diagrams which summarize data for a group of sessions:

- A histogram showing the number of sessions initiated per hour which helps to understand the load of PT Anywhere (see Figure 8).
- A histogram showing the distribution of sessions per number of user interactions.
- A scatterplot showing sessions per number of interactions and time (see Figure 9).
- A state diagram visualising the steps followed in multiple sessions. This type of visualisation helps in identifying usage patterns. For example, the state diagram of Figure 10

shows that most users start interacting with the command line interface from the very beginning without changing the simulated network topology.

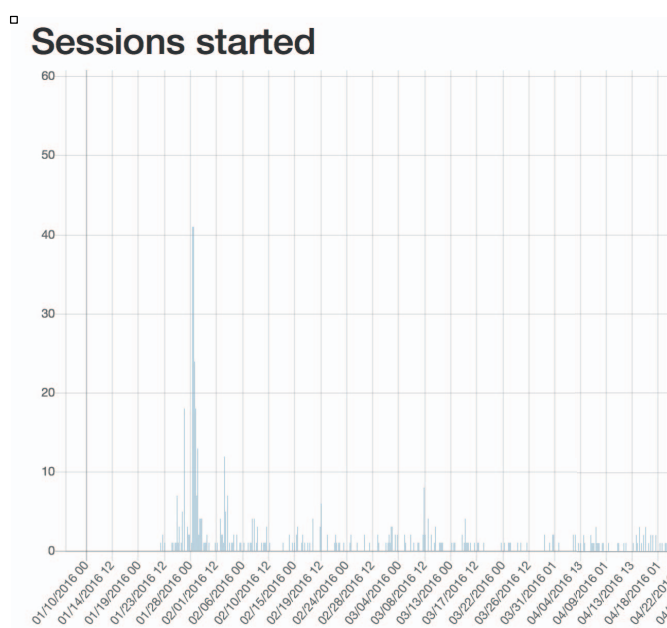


Figure 8. Histogram of PT Anywhere sessions initiated per hour.

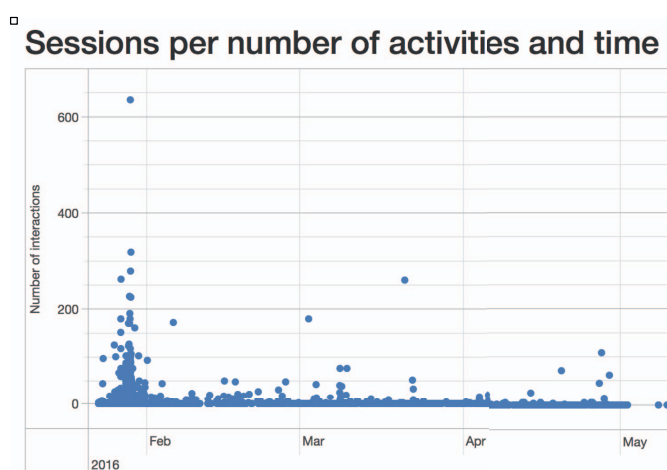


Figure 9. Scatterplot of PT Anywhere sessions per number of interactions and time.

The following visualisations are also available for each session:

- *The script of the session:* This script is an enumeration of the actions/interactions for the student (see Figure 11).
- *A state diagram:* This is a graphical representation of the steps (i.e., learning activities) that the student followed. It

²⁴ <https://tincanapi.com/registry/>

²⁵ <https://github.com/PTAnywhere/ptAnywhere-api/wiki/Vocabulary-used-to-capture-user-interaction>

is similar to the one used to visualize the steps for many sessions, but only showing the steps of one session.

- *A re-player*: This is a PT Anywhere user interface replica where the session can be replayed mimicking what the user viewed/experienced (see Figure 12). The re-player allows to restart or pause the replay and to adjust its speed (e.g., to see it 16 times faster).

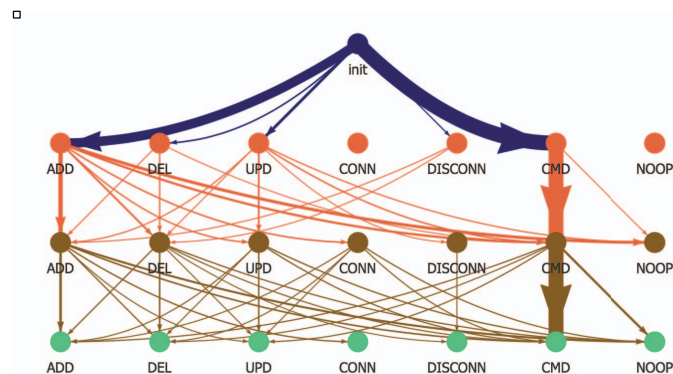


Figure 10. State diagram of the steps followed in multiple PT Anywhere sessions.

Session

1. Using MyRouter's command line
2. Using LeftHandSide's command line
3. Updating LeftHandSide
4. Using LeftHandSide's command line

```
PC>ping 10.0.0.1
Pinging 10.0.0.1 with 32 bytes of data:
Request timed out.
Request timed out.
Request timed out.
Request timed out.

Ping statistics for 10.0.0.1:
    Packets: Sent = 4, Received = 0, Lost = 4 (100% loss),

PC>ping 10.255.255.255
Pinging 10.255.255.255 with 32 bytes of data:
Request timed out.
Request timed out.
Request timed out.
Request timed out.

Ping statistics for 10.255.255.255:
    Packets: Sent = 4, Received = 0, Lost = 4 (100% loss),

PC>
```

5. Updating LeftHandSide
6. Updating LeftHandSide
7. Updating LeftHandSide
8. Using RightHandSide's command line
9. Using LeftHandSide's command line
10. Using MyRouter's command line

Figure 11. The PT Anywhere session script.

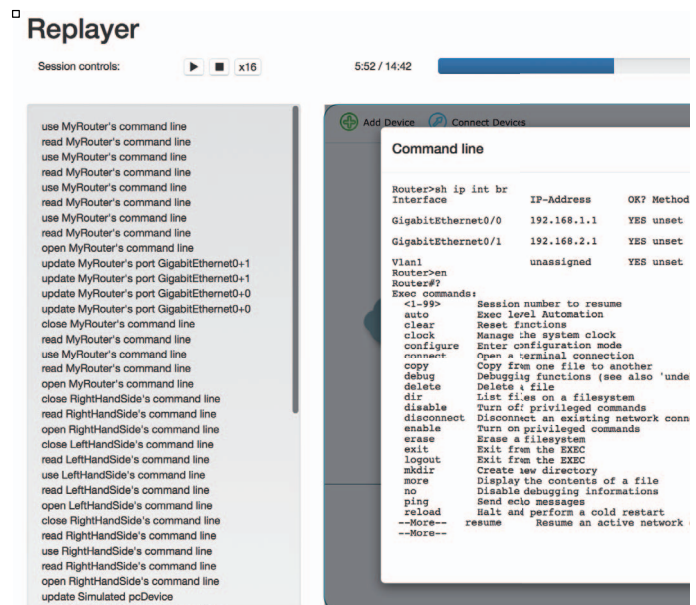


Figure 12. The PT Anywhere re-player of recorded sessions.

VI. CONCLUSIONS AND FURTHER WORK

In this paper, we have presented an initiative on teaching network engineering via online experimentation and interactive learning resources. As part of this initiative, we have been collaborating with the Cisco Networking Academy in order to produce the PT Anywhere widget, as well as a series of interactive learning materials, both based on Cisco's renowned educational software for network simulations.

Initial feedback received from tutors of the Cisco Networking Academy, suggests that this initiative has the potential to engage learners in different ways beyond the scope of the Packet Tracer software. As PT Anywhere is platform-independent, it can be used from any type of device, inside and outside the classroom, both within informal and formal learning contexts. Additionally, the use of a wide range of Learning Analytics tools for visualising the interactions of learners with the widget, offers awareness and reflection opportunities both for learners and educators. Learners can use these tools to become aware of their learning progress and compare it with that of their peers in order to further reflect on their learning experience. The PT Anywhere Learning Analytics tools can also help educators become aware of the learning progress of their students and identify potential adaptations and improvements to their learning materials and their teaching practices.

Cisco also recognises the potential of PT Anywhere as a novel learning tool, building on top of and extending both the capabilities and audience reach of the Packet Tracer software. Nuno Guarda, Head of Corporate Affairs for Cisco in the United Kingdom and Ireland, sees PT Anywhere as a "significant strategic development" and states that "while we currently reach over a million students using Packet Tracer, the

potential for the iPad and possibly HTML5 brings a new and very exciting dimension.”

The next steps of this work will focus on further improving PT Anywhere and its complementing OERs, both in terms of the pedagogy of the learning materials, as well as the functionalities offered by the widget. One of the directions we will be exploring towards improving the learning experience offered by PT Anywhere, will be in the field of accessibility. As PT Anywhere has an HTML front-end, it is easier for screen-readers to interpret it, in comparison to interpreting desktop applications like Packet Tracer. Consequently, this feature enhances the potential of PT Anywhere to act as an accessible version of Packet Tracer.

VII. ACKNOWLEDGMENT

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